Small-Field Dosimetry

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Treatment Fields

Magna-Fields

200x200 cm^2

Traditional Fields

40x40 cm^2 ⟷ 4x4 cm^2

Advance Therapy Fields

- SRS/SRT
- Gamma Knife
- Cyber-Knife
- Tomotherapy
- IMRT

Small Field

4x4 cm^2 ⟷ 0.3x0.3 cm^2

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TG-155: Small Fields and Non-Equilibrium Condition Photon Beam Dosimetry

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Misadministration Media Coverage

Springfield Hospital Reports Radiation Overdose Administered to 76 Cancer Patients

February 26, 2010

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The New York Times reported on a recent report filed by CoxHealth medical facility in Springfield, Missouri where they admitted to over-radiating 76 cancer patients during treatment. The majority of the patients were being treated for brain cancer, and received about a 50% overdose of radiation therapy. A hospital employee improperly calibrated the machine used to administer the radiation.

The New York Times — U.S.

WORLD | U.S. | N.Y. / REGION | BUSINESS | TECHNOLOGY | SCIENCE | HEALTH

POLITICS EDUCATION

Radiation Errors Reported in Missouri

By WALT BOGDANICH and REBECCA R. RUIZ
Published: February 24, 2010

A hospital in Missouri said Wednesday that it had overradiated 76 patients, the vast majority with brain cancer, during a five-year period because powerful new radiation equipment had been set up incorrectly even with a representative of the manufacturer watching as it was done.

The hospital, CoxHealth in Springfield, said half of all patients undergoing a particular type of treatment — stereotactic radiation therapy — were overdosed by about 50 percent after an unidentified medical physicist at the hospital miscalibrated the new equipment and routine checks over the next five years failed to catch the error.

Stereotactic therapy delivers radiation in such high doses that usually only one treatment is required. It is commonly used to treat small tumors in the head, which must be firmly stabilized, allowing radiation to be delivered to a precise location.

The error was discovered in September 2009 only after a second physicist received training on the equipment, made by BrainLAB, and the hospital began questioning whether the machine had been installed correctly in 2004, in a process called commissioning.

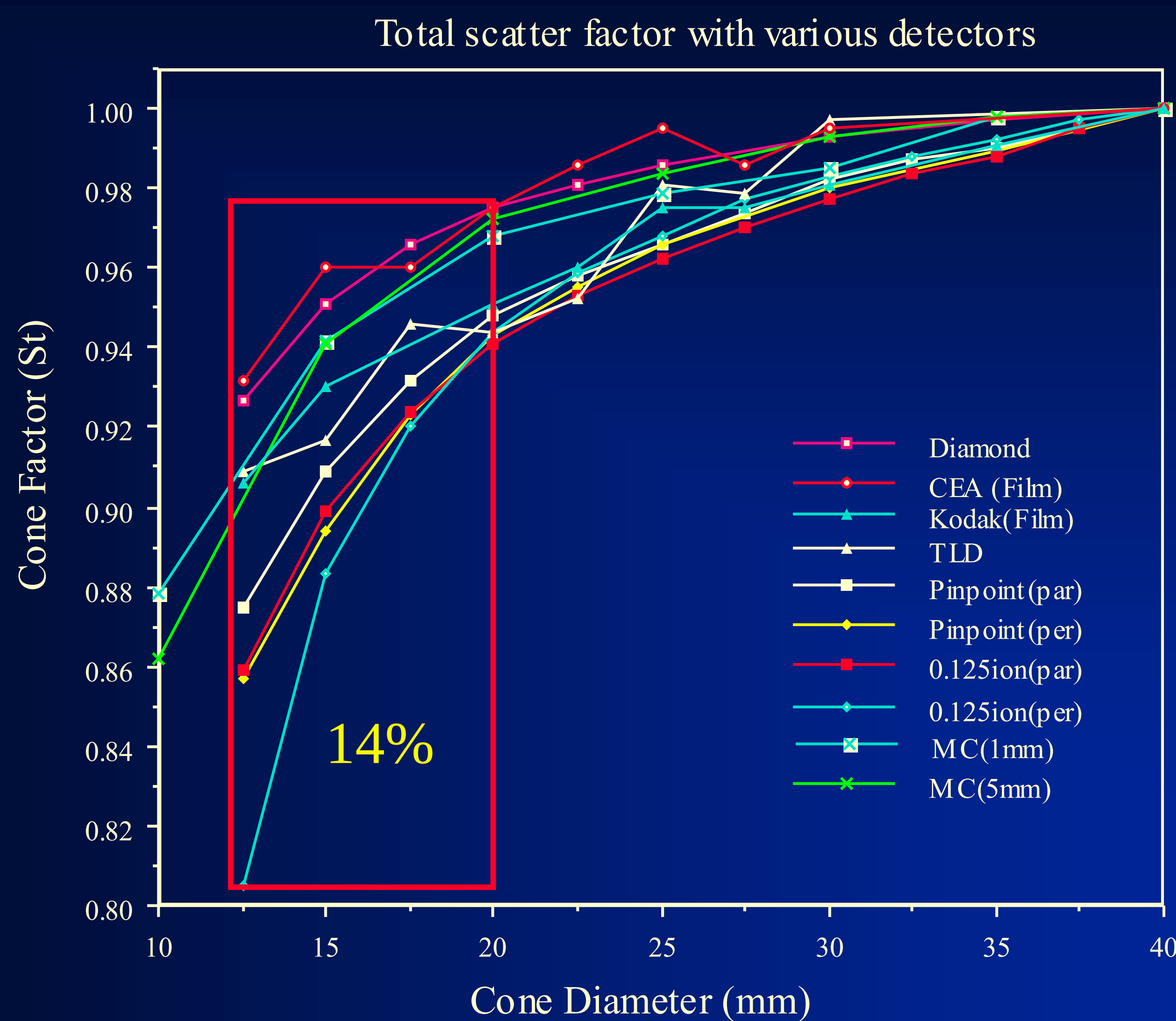
The overdoses at CoxHealth occurred in a state where there is little or no government oversight of radiation therapy, a fact that Robert H. Bezanson, the hospital's president and chief executive, chose to emphasize.

On Wednesday, he released a letter that he wrote to the Food and Drug Administration, saying that its recent decision to toughen oversight of diagnostic radiation did not go far enough.

"The initiative should be broadened to include regulation of medical radiation therapy as well," he wrote. "We have also learned that the incident here at CoxHealth is, unfortunately, not an isolated occurrence. Rather, similar instances of medical overradiation have occurred at other hospitals throughout the country. Without increased regulation and oversight, these instances of medical overradiation will likely continue."

Wrong detector used for BrainLab cone calibration

Dosimetric Variation with Detectors



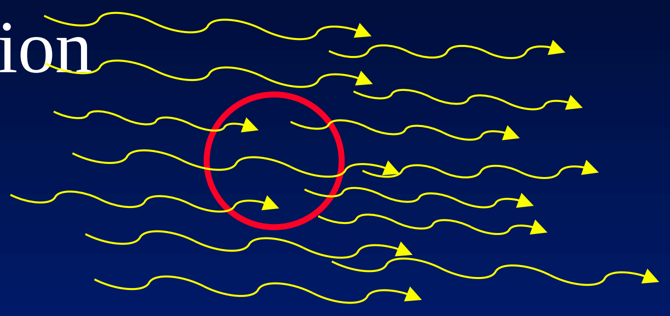
Das et al, J Radiosurgery, 3, 177-186, 2000

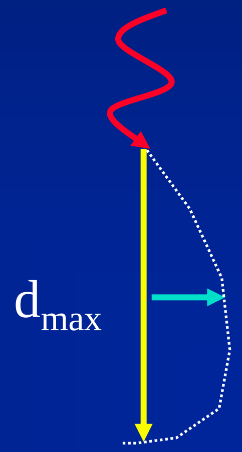
What is a Small Field?

- Lack of charged particle
  - Dependent on the range of secondary electrons
  - Photon energy
- Collimator setting that obstructs the source size
- Detector size is comparable to the field size

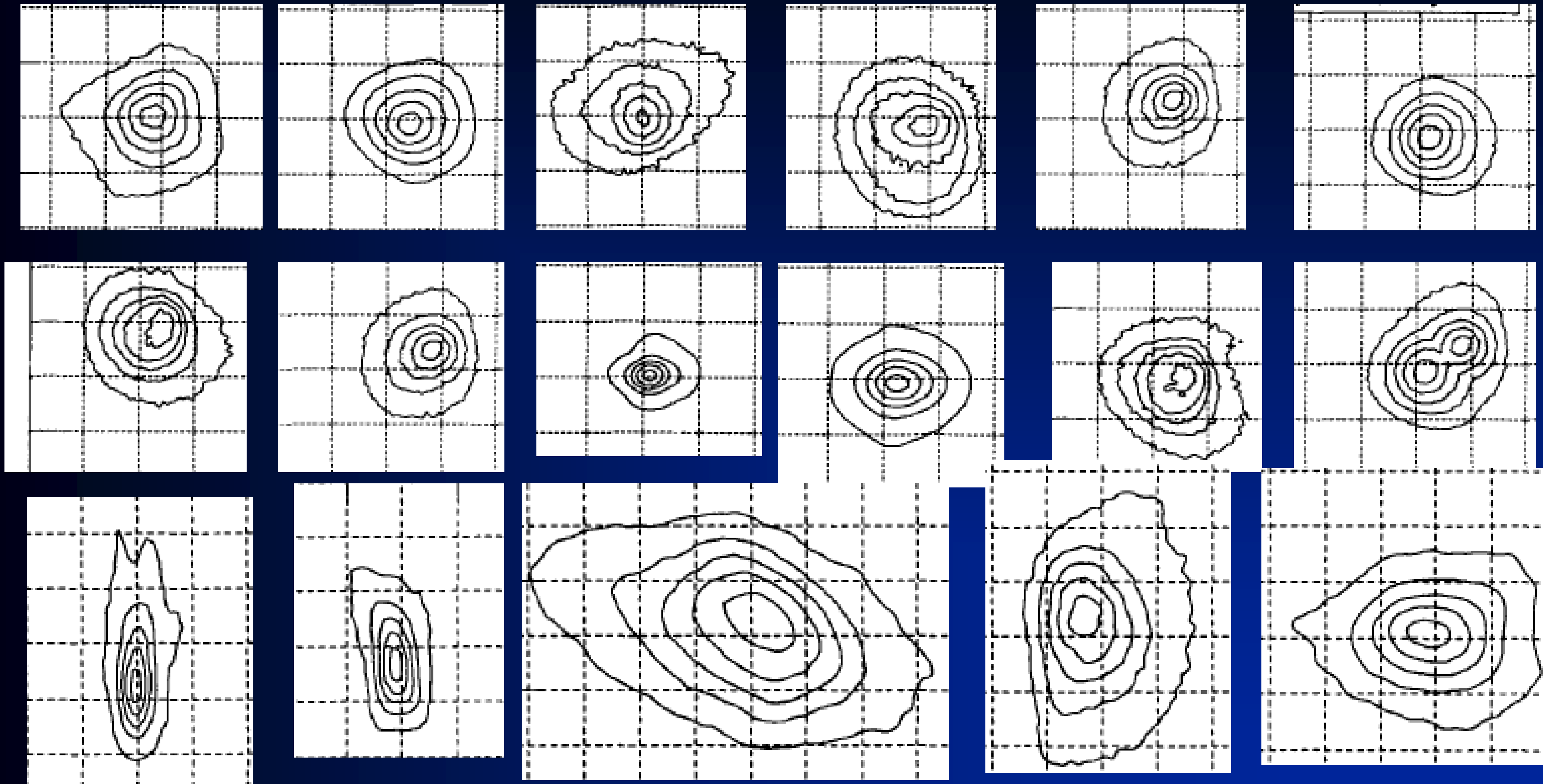
Electron Range & LCPE

- Electron range= d_{max} in forward direction
- Lateral Charged Particle Equilibrium
- Electron range in lateral direction
  - Nearly energy independent
  - Nearly equal to penumbra (8-10 mm)
- Field size needed for LCPE
  - Lateral range
  - 16-20 mm





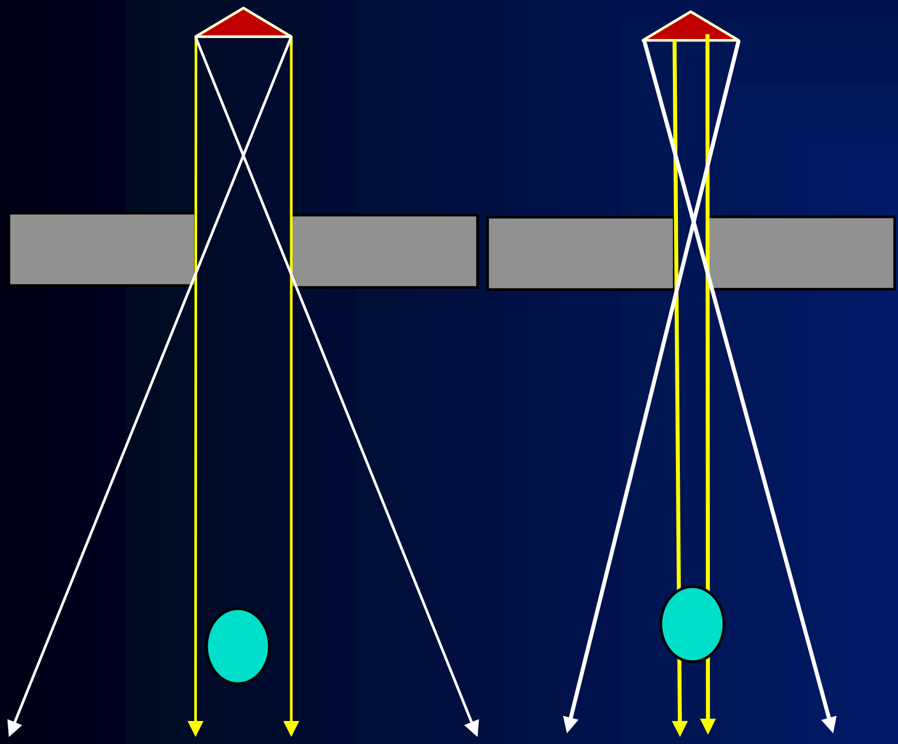
Source Size

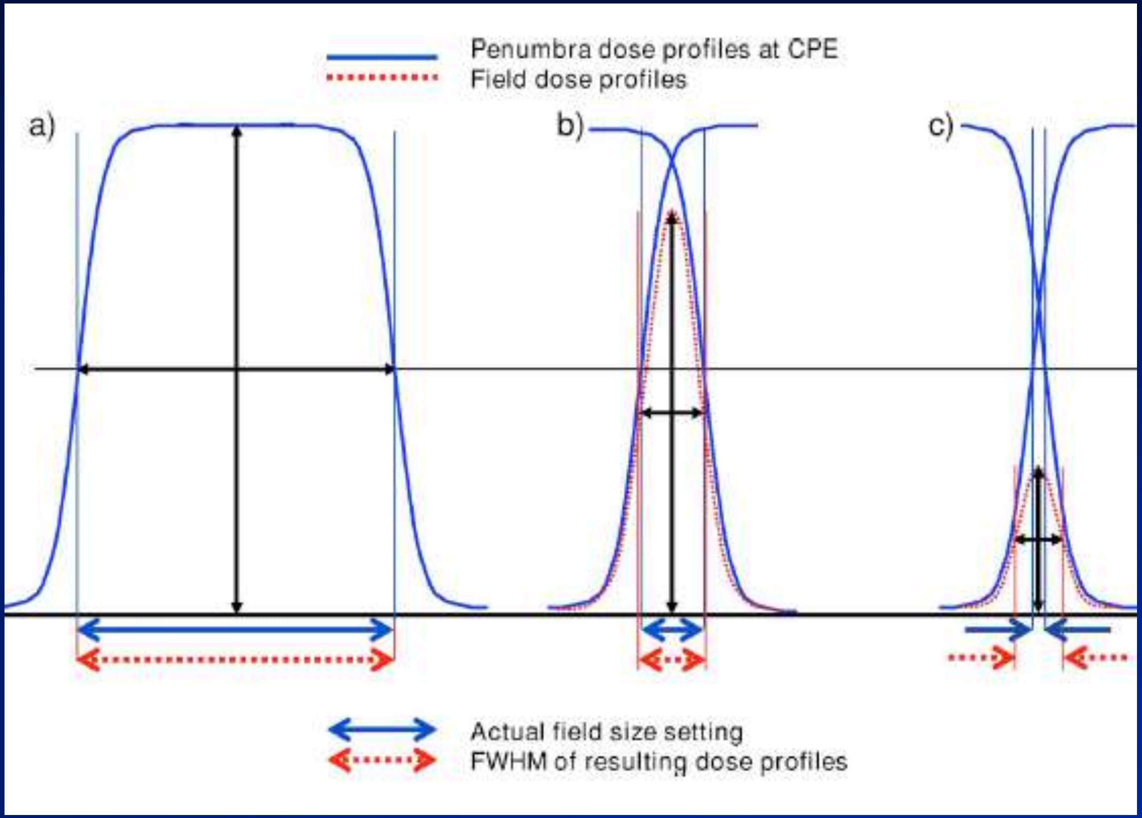


90%, 70%, 50%, 30%, 10% iso-intensity line

Jaffray et al, Med Phys 20, 1417-1427 (1993)

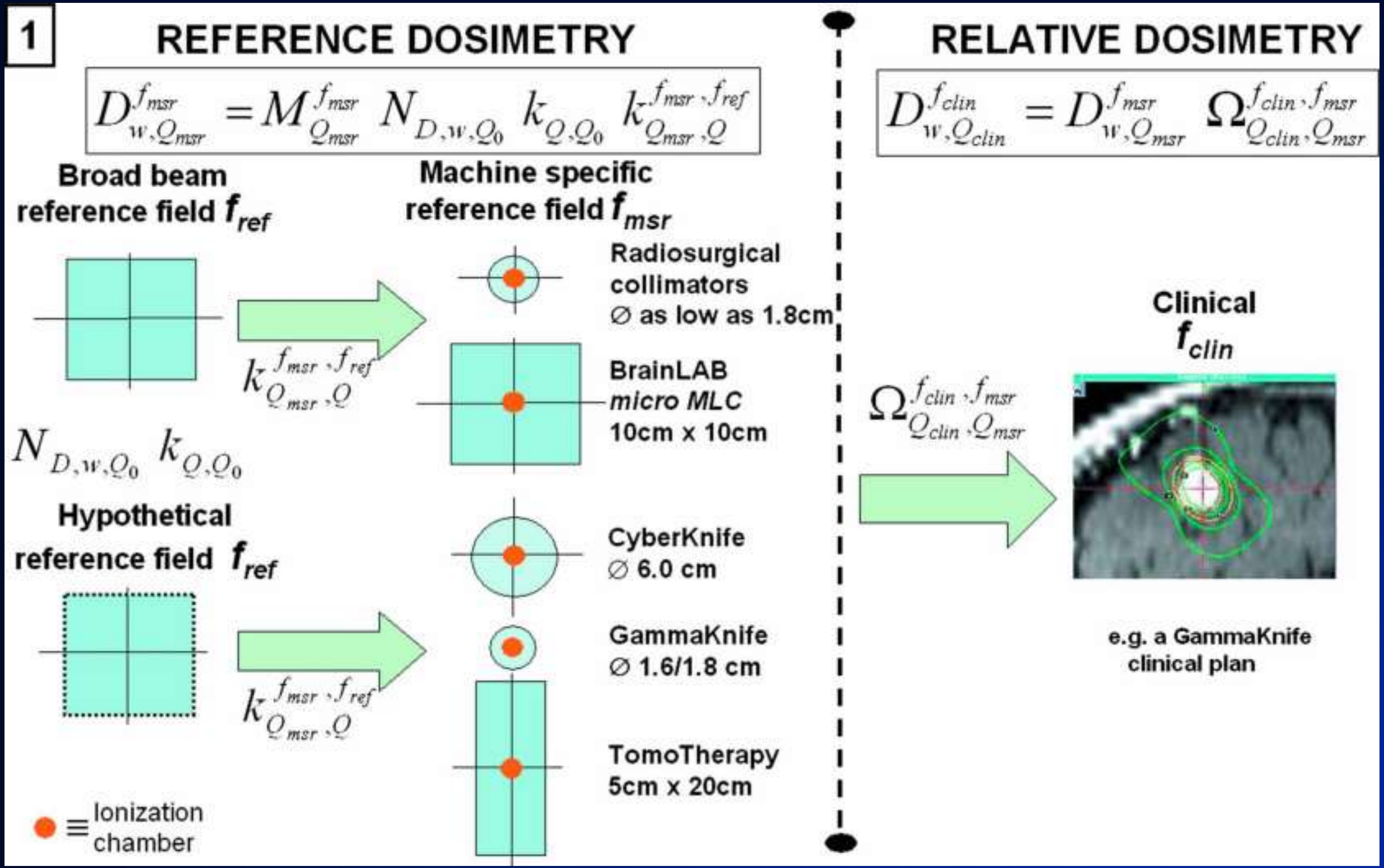
Definition of Small Fields





Das et al, Med. Phys. 35, 206-215, 2008

IAEA/AAPM proposed pathway



*Alfonso, et al. Med Phys **35**, 5179-5186 (2008)*

Relative Dosimetry

$$D_{w,Q_{msr}}^{f_{msr}} = M_{Q_{msr}}^{f_{msr}} N_{DW,Qo} \boxed{k_{Q,Qo}} \boxed{k_{Q_{msr},Q}^{f_{msr},f_{ref}}}$$

$$\Omega_{Q_{clin}Q_{msr}}^{f_{clin}f_{msr}} = \frac{M_{Q_{clin}}^{f_{clin}}}{M_{Q_{msr}}^{f_{msr}}}\left[\frac{\left(D_{w,Q_{clin}}^{f_{clin}}\right)/\left(M_{Q_{clin}}^{f_{clin}}\right)}{\left(D_{w,Q_{msr}}^{f_{msr}}\right)/\left(M_{Q_{msr}}^{f_{msr}}\right)}\right] = \frac{M_{Q_{clin}}^{f_{clin}}}{M_{Q_{msr}}^{f_{msr}}} k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$$

$$k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}} = \frac{\left(D_{w,Q_{clin}}^{f_{msr}}\right)/\left(M_{w,Q_{clin}}^{f_{clin}}\right)}{\left(D_{w,Q_{msr}}^{f_{clin}}\right)/\left(M_{w,Q_{msr}}^{f_{clin}}\right)} = \frac{(Output)_{rel}}{(\mathrm{Re}\,ading)_{rel}}$$

$$k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}} = \frac{(S_{w,air})_{fclin} \cdot P_{fclin}}{(S_{w,air})_{fmsr} \cdot P_{msr}}$$

Why So Much of Fuss?

- Reference (ref) conditions cannot be achieved for most SRS devices (cyberknife, gammaknife, tomotherapy etc)
- Machine Specific reference (msr) needs to be linked to ref
- Ratio of reading (PDD, TMR, Output etc) is not the same as ratio of dose

$$\boxed{\frac{D_1}{D_2} \neq \frac{M_1}{M_2}}$$

$$\boxed{\frac{D_1}{D_2} = \frac{M_1}{M_2} \bullet \left[k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}} \right]}$$

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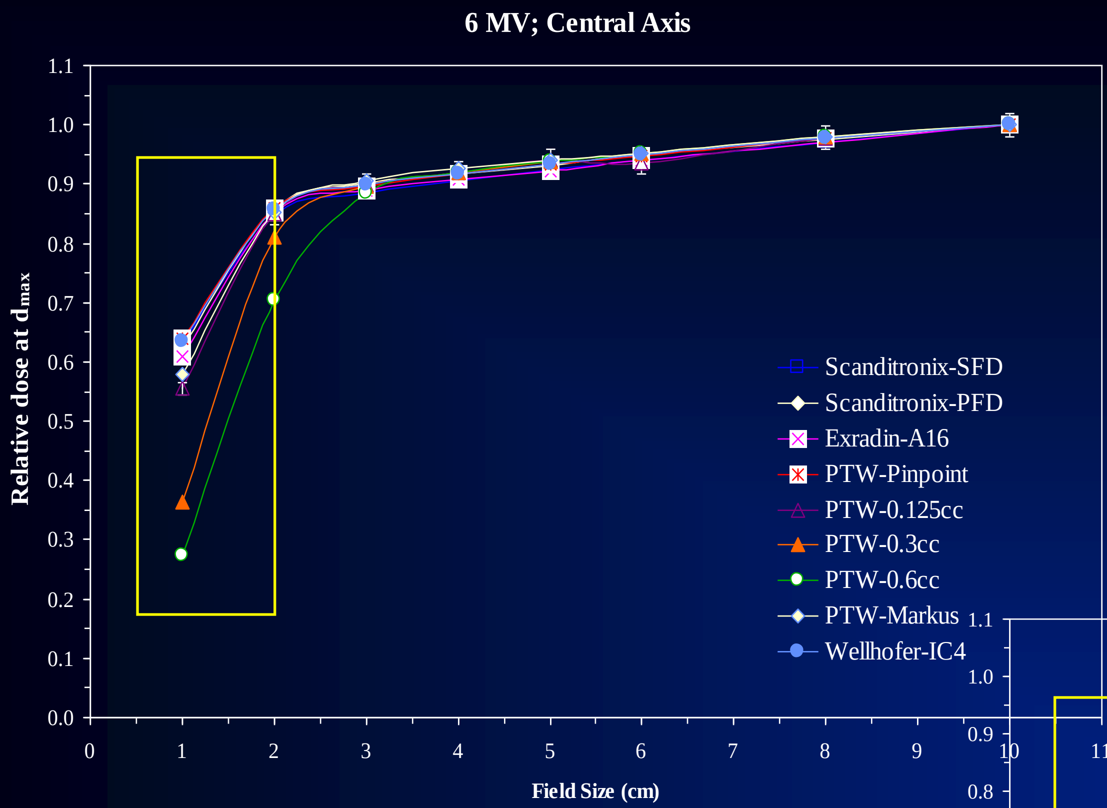
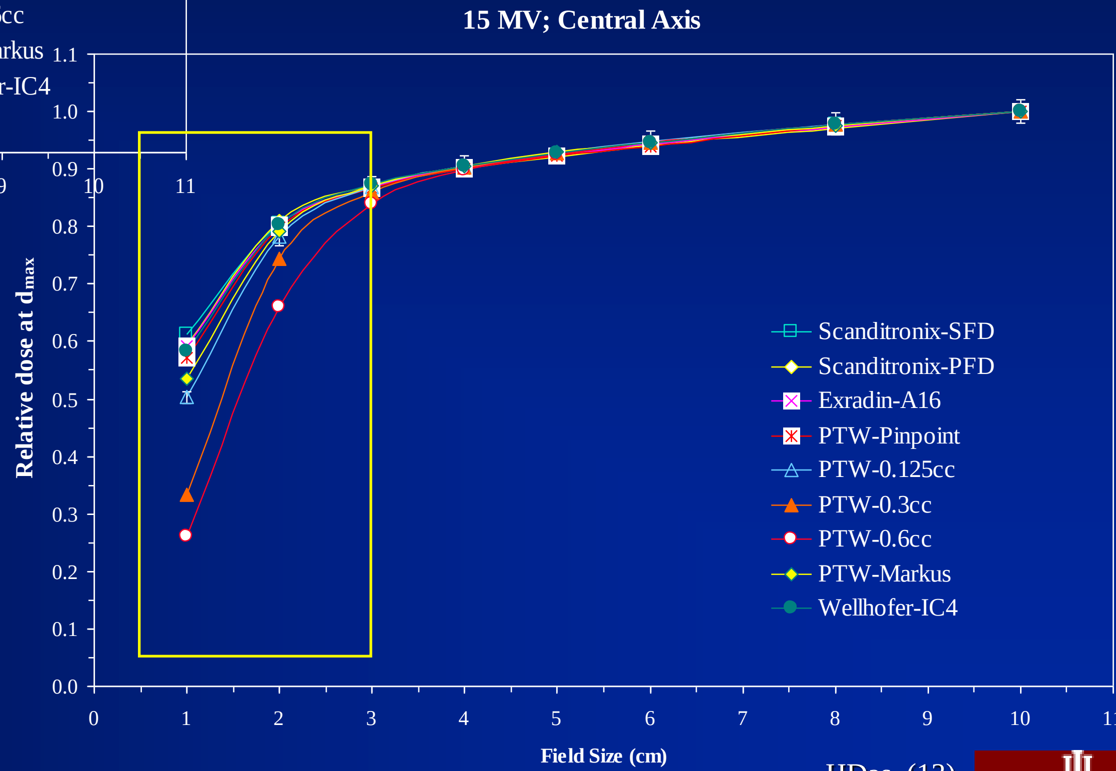
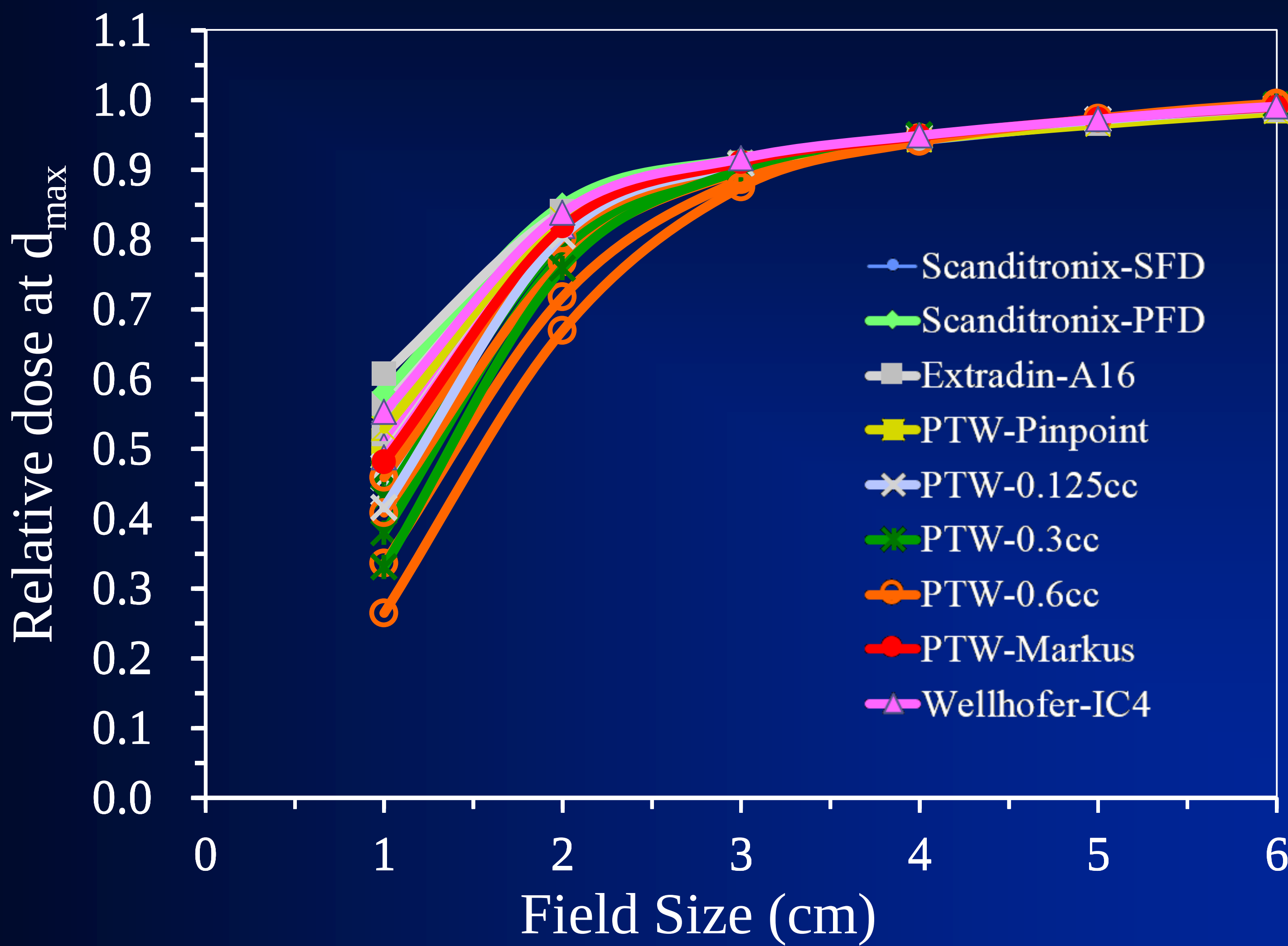
Field Size Limit for Accurate Dose Measurements with Available Detectors





Das et al, TG-106, Med Phys, 35, 4186, 2008

Impact of $k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$



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Correction Factors

Correction Factor depends on:

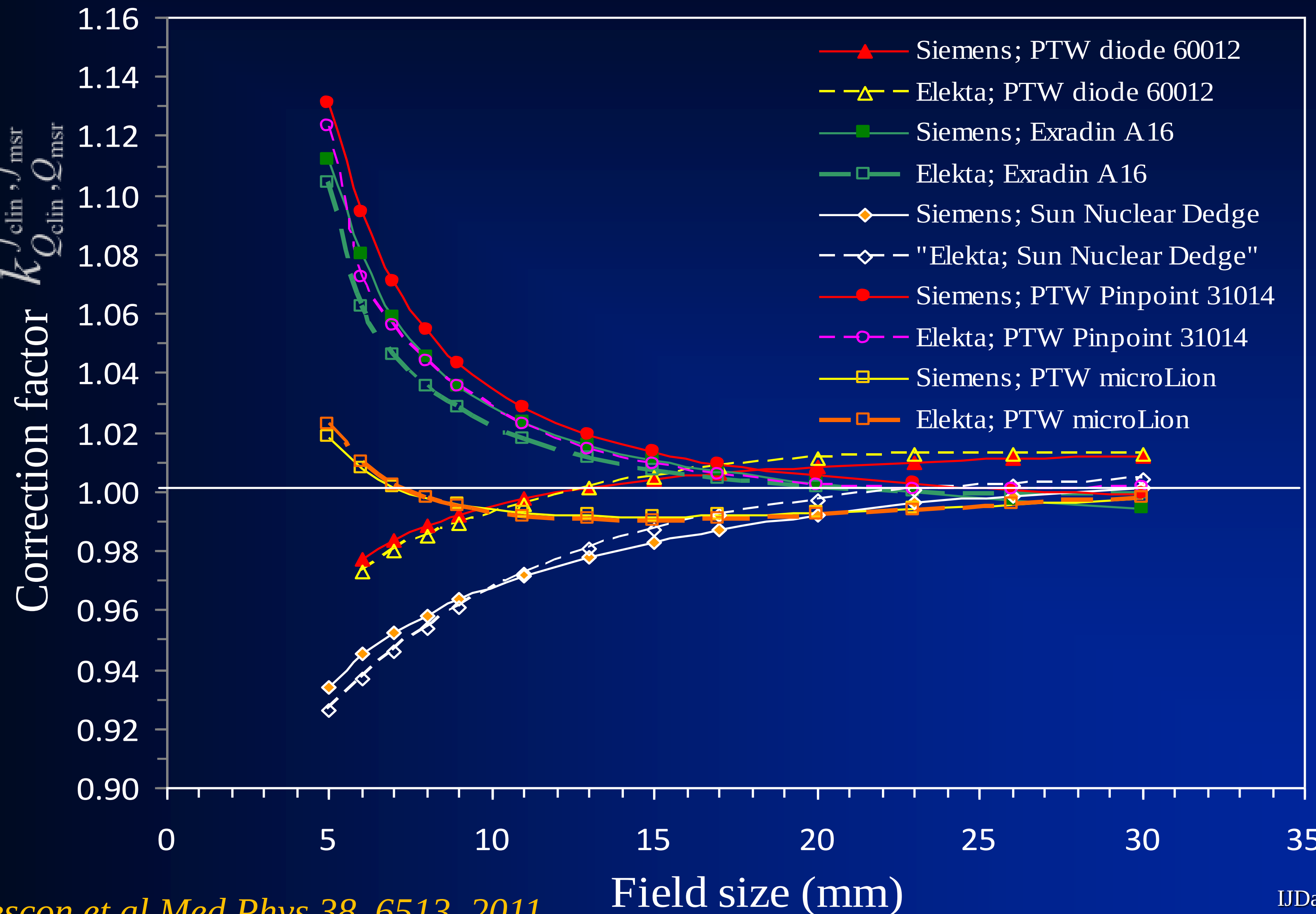
- Field size
- Source size (FWHM)
- Detector type

TABLE VII. F_{corr} of the four detectors for the 5, 7.5, and 10 mm collimators, as a function of the FWHM.

A16	F_{corr}		
FWHM (mm)	5 mm coll	7.5 mm coll	10 mm coll
1.4	1.067	1.021	1.008
1.8	1.087	1.017	1.007
2.2	1.102	1.020	1.012
2.6	1.112	1.027	1.010
Pin Point	F_{corr}		
FWHM (mm)	5 mm coll	7.5 mm coll	10 mm coll
1.4	1.082	1.025	1.017
1.8	1.099	1.024	1.013
2.2	1.110	1.025	1.013
2.6	1.124	1.037	1.016
Diode	F_{corr}		
FWHM (mm)	5 mm coll	7.5 mm coll	10 mm coll
1.4	0.953	0.966	0.978
1.8	0.955	0.966	0.978
2.2	0.957	0.967	0.978
2.6	0.940	0.967	0.978
Diamond	F_{corr}		
FWHM (mm)	5 mm coll	7.5 mm coll	10 mm coll
1.4	1.066	1.001	1.001
1.8	1.093	1.007	1.000
2.2	1.107	1.010	0.999
2.6	1.123	1.012	1.001

Francescon, et al Med Phys 35, 504, 2008

Published data on $k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$



Francescon et al Med Phys,38, 6513, 2011

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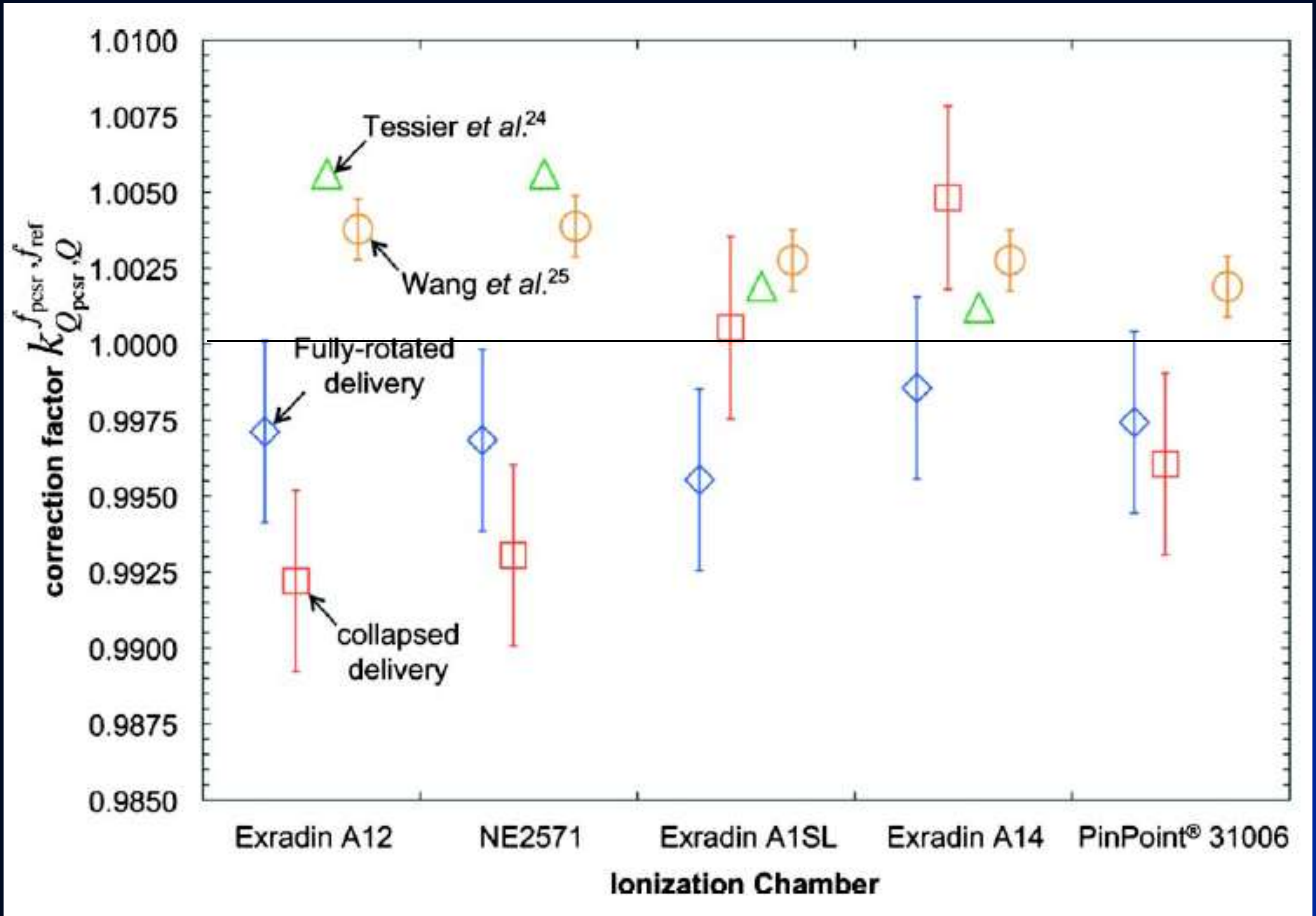
$k_{Q_{\text{clin}},Q_{\text{msr}}}^{f_{\text{clin}},f_{\text{msr}}}$ Correction Factor vs Ion Chambers



Chung et al , Med Phys, 37, 2404-2413, 2010

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$k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$ of Linear Accelerators (Varian)

Implementing a newly proposed Monte Carlo based small field dosimetry formalism for a comprehensive set of diode detectors

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Med. Phys. 38 (12), 6992, 2011

$k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$ of Linear Accelerators

Calculation of $k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$ for several small detectors and for two linear accelerators using Monte Carlo simulations

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Med. Phys. 38 (12), 6513-6527, 2011

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Experimental small field 6 MV output ratio analysis for various diode detector and accelerator combinations

Gavin Cranmer-Sargison [a,b,*], Steve Weston [b,c], Narinder P. Sidhu [a,d], David I. Thwaites [b,e]

Radiotherapy and Oncology 100 (2011) 429–435

$k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$ Cyber Knife

	5 mm		7.5 mm		10 mm	
Detector	$M_{Q_{clin}}^{f_{clin}} / M_{Q_{msr}}^{f_{msr}}$	$k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$	$M_{Q_{clin}}^{f_{clin}} / M_{Q_{msr}}^{f_{msr}}$	$k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$	$M_{Q_{clin}}^{f_{clin}} / M_{Q_{msr}}^{f_{msr}}$	$k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$
A16	0.626 (15)	1.089 (3)	0.811 (10)	1.018 (3)	0.866 (6)	1.010 (3)
PinPoint	0.620 (17)	1.101 (3)	0.801 (7)	1.024 (3)	0.862 (5)	1.015 (3)
Diode 60008	0.726 (1)	0.943 (3)	0.873 (1)	0.949 (3)	0.912 (1)	0.964 (3)
Diode 60012	0.705 (1)	0.956 (3)	0.847 (2)	0.966 (3)	0.891 (1)	0.978 (3)
EDGE	0.726 (1)	0.948 (3)	0.864 (1)	0.955 (3)	0.906 (1)	0.966 (3)
Alanine	0.544 (8)	1.249 (8)	0.785 (12)	1.059 (4)	0.855 (13)	1.019 (3)
TLD	0.668 (4)	···	0.809 (6)	···	0.880 (8)	···
EBT films	0.659 (17)	···	0.811 (16)	···	0.853 (18)	···
Polymer gels[a]	0.702 (21)	···	0.872 (27)	···	0.929 (29)	···

Pantelis et al, Med Phy. 37, 2369-2379, 2010

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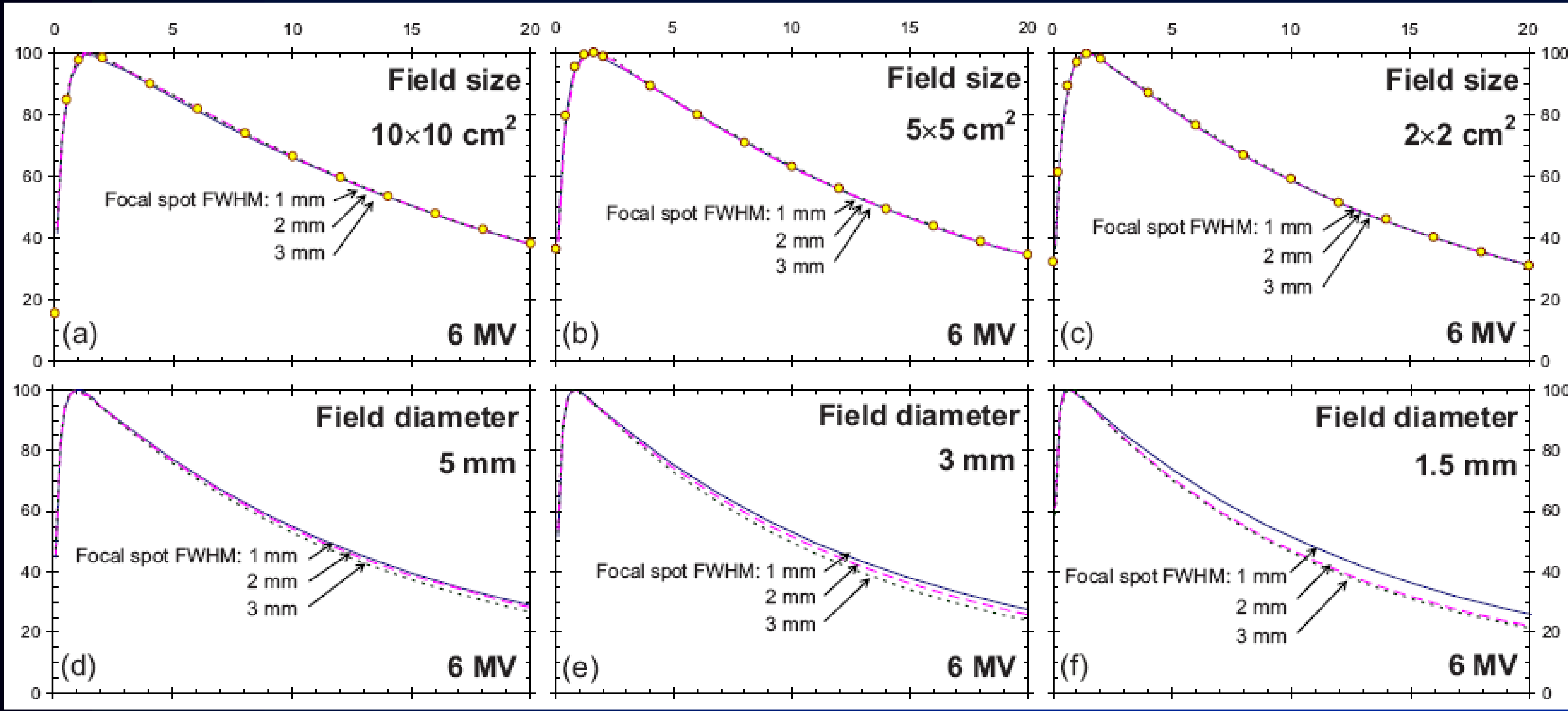
Take Home Message

- Small field definition is dependent of the beam energy
- Stopping power ratio in small fields for most ion chambers is relatively insensitive to field size and is same as the reference field
- IAEA and AAPM working on guidelines for absolute dosimetry of small fields
- $k_{Q_{\mathrm{clin}},Q_{\mathrm{msr}}}^{f_{\mathrm{clin}},f_{\mathrm{msr}}}$ factor converts reading to dose and depends on
  - Machine type
  - Source size
  - Detector
- TG-155 will provide guidelines for relative dosimetry

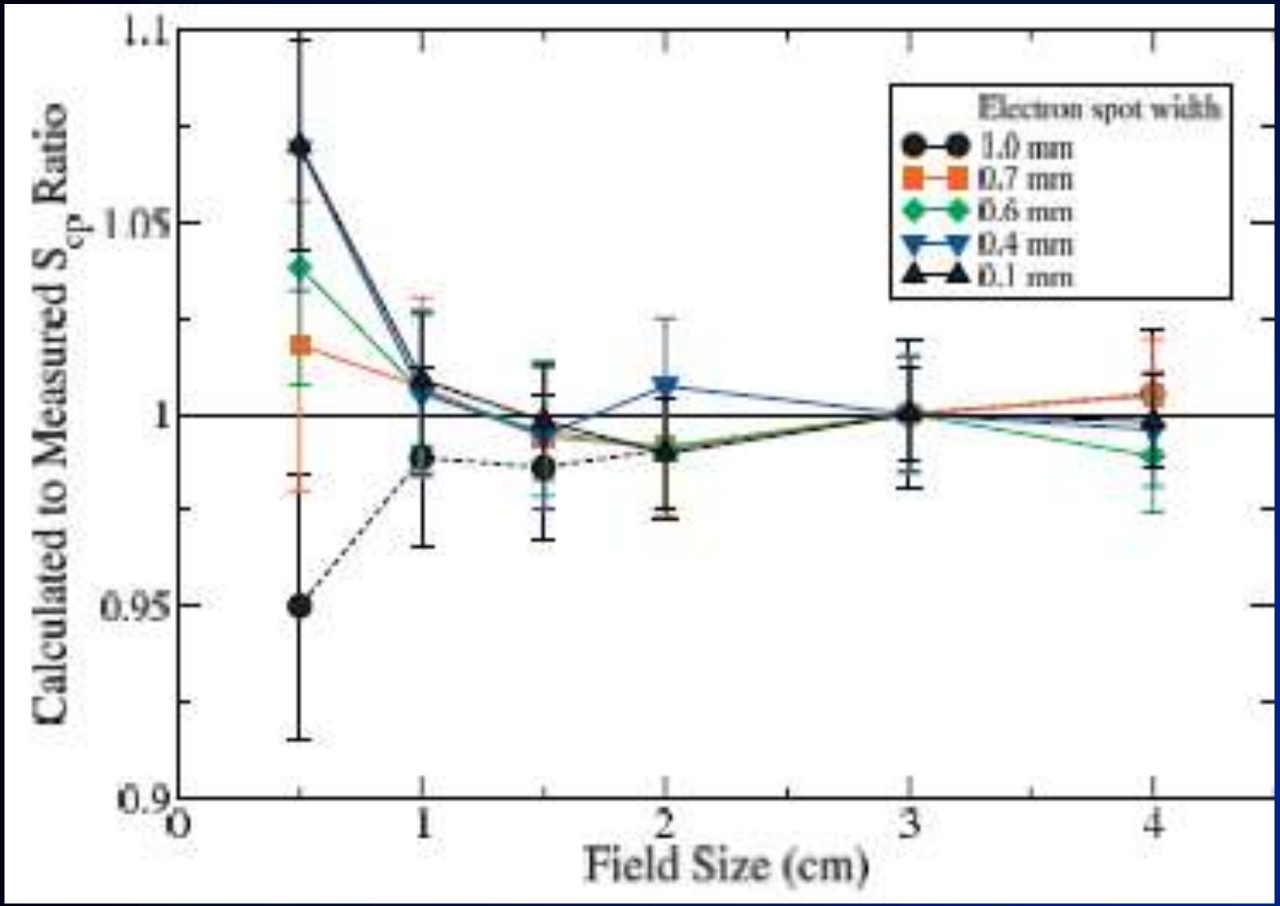

Thanks

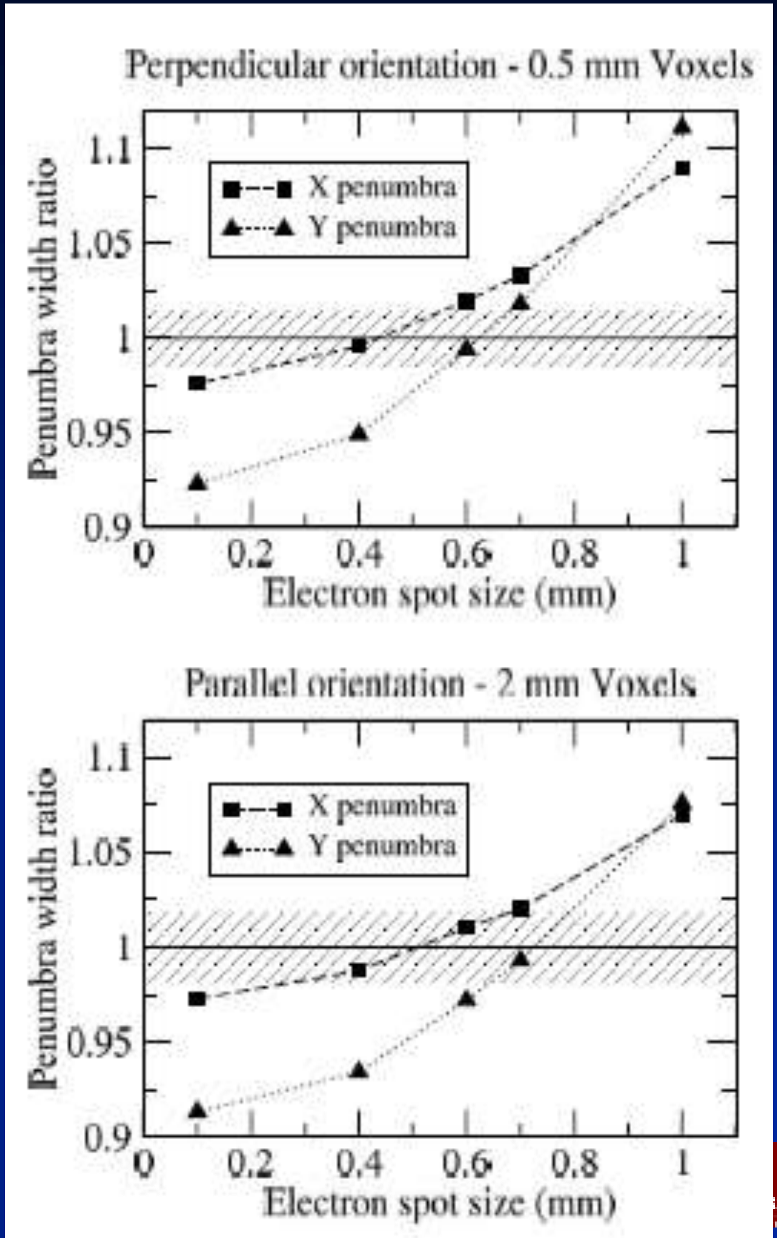
Depth Dose & Source Size



Sham et al, Med Phys, 35, 3317-3330, 2008

Dose and Penumbra with Spot Size





Scott et al, Med Phys, 36, 3132, 2009